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A RESEARCH AGENDA FOR FIRE PROTECTION ENGINEERING

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Notice

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Why Engineers Need Fire Research to Better Serve Society

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INTRODUCTION

"Fire protection engineering" is the application of scientific and engineering principles to protect people and their environment from destructive fire. As the primary appliers of fire protection research, fire protection engineers form one of the principal links between researchers and the end users of fire protection technology.

Fire protection engineering uses a number of strategies to provide the safety required by society at the most reasonable cost. These include:

- Hazard and risk analysis,
- Building design, construction, and arrangement,
- Design, installation and maintenance of fire detection and suppression and detection systems, and
- Post-fire investigation and analysis.

Fire protection engineers are but one of a number of professional groups that are involved with fire safety. Other allied professional groups include building owners and managers, building and fire officials, the fire service, product manufacturers, and the educational and legal communities. Society ultimately faces the burden caused by unwanted fire, and each of these groups has a role to play in reducing this burden.

The fire burden can be felt in a number of areas: life safety, costs of fire losses, costs associated with protecting against fire, and environmental damage. To make significant progress in reducing the fire burden requires research and the application of research. However, it is important to take a measured approach towards research, as there is a limited funding base to finance research. Such an approach should prioritize which research would have the greatest impact towards reducing the fire burden.

THE FIRE BURDEN

The fire burden is felt in a number of areas. Each is discussed in detail below.

Life Safety

In 1986, the average annual fire death rate among 15 industrialized nations was 14.4 per million population.[1] In the United States, the fire death rate was slightly higher, at a total of 5850 or 24.4 per million in 1986 and 4585, or 17.4 per million in 1995.[2] While this represents almost a 30% decrease in the U.S. over ten years, the fire death rate per million population in the U.S. is still two to three times that of several European nations.[2]

In the U.S., several population groups have a disproportionate share of the death rate. Children less than five years old have double the death rate of the entire population. Adults over 60 years of age also have a fire death rate higher than the general population.[2] As the percentage of older people living in the U.S. is expected to increase over the coming years, and this age group has a higher than average fire death rate, the aging of the population may exert a negative pressure on the decreasing trend of the overall death rate.

Within the United States, the majority of fire deaths, 74%, occur in homes,[2] with the vast majority of residential fire deaths occurring in one- and two-family homes. Vehicle fires constitute approximately 10%[2] of the fire deaths and outdoor fires constitute 4%[2]. Only roughly 7% of the fire deaths occurred in commercial settings, where the majority of fire protection attention is presently focused.

Conclusions that can be drawn from these statistics include: (1) the fire death rate in the U.S. is worse than the average of industrialized nations, and (2) there are forces that will make it more difficult to continue the downward trend in fire deaths. Research can help engineers find methods of protecting people that can be used to lower fire death rates. The use of this research would improve life safety for everyone.

Fire related costs

In 1994, the average direct cost of fire losses in several industrialized countries was 0.2% of their respective gross domestic products. In the United States, the 1997 total direct dollar loss was approximately $8.5 billion[3], or 0.15% of the gross domestic product. This figure includes fire damage to structures, contents, vehicles, machinery, etc., and does not include dollar losses associated with lost business or market share.

However, the total cost of fire in the U.S., including direct losses, indirect losses, and the cost of fire protection, insurance and fire departments, is estimated at a staggering $100 – 200 billion per year[4], or approximately 2% of the U.S. gross domestic product.

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[1] Tudhope, H., "International Fire Losses" 1985-1987, *Fire Prevention*, May 1989.
[2] "Fire in the United States," U.S. Fire Administration, 10th Edition, 1998.
[3] Karter, M. "1997 Fire Loss in the U.S.," NFPA Journal, National Fire protection Association, September/October. 1998, pp. 72 – 82.
[4] Wilmot, R.T.D. (Ed.), "United Nations Fire Statistics Study," World Fire Statistics Center, London: September, 1998.

Research can help engineers find cost effective methods of protecting people and property that can decrease the total cost of fire. The use of this research would increase the quality of life for everyone by lowering the total amount spent on fire and fire protection, freeing those financial resources for other uses.

International competitiveness

The average cost of installing fire protection into buildings in several industrialized countries ranges from 2-4% of the total construction cost. In the U.S., this cost ranges from 2.5% for housing to 12% for private, non-residential structures.[4] This cost differential of fire protection in buildings is passed on to the cost of products and services of the organizations that inhabit those buildings, which can impact international competitiveness.

Research can be used to identify methods to decrease the cost of built-in fire protection. The application of this research would help reduce the building cost differential among industrialized countries, which would facilitate international competitiveness.

International trade

Many products that are used in the built environment require fire performance related testing. Active and passive fire protection products require testing to demonstrate their capabilities. Other types of products require testing to ensure that they do not negatively impact fire behavior in the built environment.

Typically, the tests associated with having products approved vary slightly from country to country. This requires manufacturers to conduct a number of similar, but different, tests on a single product to market it in the global marketplace. The cost associated with conducting this testing is estimated at $25 billion per year.[5] These testing-related costs are passed on to the consumer as increased product costs.

Research can be used to develop scientifically based, performance oriented test methods for products and materials. The implementation of these test methods would allow for different countries to select different pass-fail criteria in accordance with their own desired level of safety, but make it necessary for a manufacturer to only test a product once. Where performance-based design is used, different pass-fail criteria could be specified by the designer depending on the hazards of the building.

Environmental protection

Both fire and fire protection measures can have a detrimental impact on the environment. Uncontrolled fires in manufacturing, production or storage facilities can release hazardous products of combustion into the air. Runoff from fires and fire fighting systems can release

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[5] Hall, J. "The Total Cost of Fire in the United States Through 1995," NFPA Fire Analysis and Research Division, Quincy, MA, March 1998.

hazardous substances. Also, fire suppression agents, such as Halon, CO_2, and emerging substitutes can impose environmental or health hazards of their own.

Research can be used to identify improved methods of property protection to mitigate the risk or hazard of fire. Research can also be used to find environmentally benign fire protection methods and agents. The application of this research would result in improved environmental protection.

APPLICATION OF RESEARCH

Traditionally, research results were applied through modifications to prescriptive codes and standards. Unfortunately, the time lag between research completion and the application of research through code modification was often very long.[6]

The time lag resulted from overcoming a number of barriers before the research results could be incorporated into the relevant code or standard. These steps have been described as:[6]

- Research, i.e., conducting and completing the research
- Technology transfer
- Application, typically to support code equivalencies or deviations
- Awareness by those outside of the fire protection engineering community
- Acceptance within the building community
- Approval by incorporation of the research into the relevant code

It is noteworthy that the research results would typically be applied prior to final acceptance through code equivalencies, however, this practice only allowed for limited application of the research.

Some examples

Three examples illustrate the impact of research on the practice of fire protection engineering and the speed that research results can be applied. These examples are sprinkler hydraulic calculations, smoke control, and replacement of Halon.

Prior to the 1970's, pipe sizes in sprinkler systems were selected based on pipe schedules. These schedules listed the maximum number of sprinklers that could be supplied for a given pipe size. Application of these pipe schedules required only minimum consideration of the water supply. The ability to perform sprinkler system hydraulic calculations, which would allow pipes to be sized based on the available water supply, dated to 1905.[7] However, hydraulic calculation methods were not included in NFPA 13 until the 1970's, and the pipe schedule method was not eliminated until the 1990's.[6]

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[6] Quiter, J. "Fire Research and Its Impact on the Building Code," in *Proceedings of the Conference on Firesafety Design in the 21st Century*, Worcester Polytechnic Institute, Worcester, MA: 1991.
[7] Williams, G. & Hazen, A. *Hydraulic Tables*, John Wiley & Sons, New York: 1905.

Calculation of smoke development and smoke spread has been the topic of basic research and applied research for many years. In the late 1960s and early 1970s, significant work was done on smoke spread within malls by researchers in the UK. Butcher and Parnell wrote a book on smoke control in the late 70's[8], and Klote and Milke have published several books and articles, including *Design of Smoke Management Systems*[9], in the years since. In the late 1980s, this information was incorporated into recommended practices [10, 11], and in the early 1990s was introduced as code into the *Uniform Building Code.* Similar language will also be included in the Year 2000 edition of the *International Building Code.*

There are still issues that need to be resolved regarding design of smoke control systems. The appropriate fire source needs to be better quantified, although there is limited, although growing, information regarding expected fire sizes in various occupancies and layouts. The reliability of the equipment and the overall system needs to be better understood. Building construction methods, including anticipated leakage of walls and barriers, and their impact on smoke management system performance needs further study. Other areas that could use further research include the responsiveness of the overall system and its individual components and how the quality of construction of the mechanical systems impacts performance.

With regard to smoke, there are several areas where further information is needed. They include information on the smoke hazard associated with various types of fires, smoke production from fire sources, including species yields, and how people are affected by smoke, including toxicity and visibility.

The recent work regarding Halon replacement shows a much faster progression. Several years ago, the problem of ozone depletion was noted as an environmental issue. A political solution was reached that eliminated production of Halon over time. This action created a need to replace Halon systems with another viable protection method. The response was a significant amount of money, energy, and time. As a result, several new products and methods have been developed.

Why is it that the Halon replacement project moved so quickly whereas research and its application on automatic sprinklers and smoke control has moved so slowly? A primary reason is that an externally induced (political) time factor was placed on the overall development of new materials and systems. This caused a direct financial impact and an immediate need for development of research and application of that research. This external inducement was not present for smoke control research or automatic sprinkler research. Rather, the only inducement in those cases was better fire protection methods and products. Some means of developing the "carrot" may be necessary to move research forward more quickly.

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[8] Butcher, E. & Parnell, A. *Smoke Control in Fire Safety Design*, London, E. & F.N. Spon: 1979.
[9] Klote, J. & Milke, J. *Design of Smoke Management Systems*, American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta: 1992.
[10] *Recommended Practice for Smoke-Control Systems*, NFPA 92A, National Fire Protection Association, Quincy, MA, 1996.
[11] *Guide for Smoke Management Systems in Malls, Atria and Large Areas*, NFPA 92B, National Fire Protection Association, Quincy, MA, 1995.

Changes are now occurring that will allow for expedited implementation of research results. The acceptance of performance-based fire protection engineering is becoming more widespread. Several countries have adopted or are in the process of adopting performance-based fire protection engineering methodologies, including Australia, New Zealand, the United Kingdom and the Nordic countries[12]. In the U.S., two performance-based codes have been published or will be published soon: a performance option in the National Fire Protection Association's *Life Safety Code*[13] and a new *International Building Performance Code*[14]. Additionally, the Society of Fire Protection Engineers published a performance-based fire protection engineering design guide[15] to facilitate the implementation of these performance-based codes.

While the acceptance and implementation of performance-based codes will not overcome all of the barriers listed above, it will eliminate some of the barriers and shorten others. Additionally, preparing guidance on the application of research, an activity that the Society of Fire Protection Engineers presently has underway in several areas, will further aid the acceptance of fire research results.

However, performance-based codes bring with themselves new challenges that point to a need for further research. There are gaps in the knowledge base that will affect the widespread acceptance and implementation of performance-based codes. These gaps occur in many areas that would be considered in performance-based design, such as prediction of time dependent heat release rates, prediction of detection system response, prediction of suppression system effectiveness, and prediction of available safe egress time or required safe egress time.[16]

While the absence of a detailed understanding in these areas will not in itself form a barrier to the implementation of performance-based codes, it will hamper the realization of the full cost effectiveness of performance-based codes. Where a detailed understanding of a given phenomenon does not exist, a reasonable estimation may be made. However, these assumptions should be conservative enough that the final design is robust.

Conservative assumptions have the advantage of adding additional assurance to the final design, but also bring the disadvantage of added cost. These added costs become increasingly large where a number of conservative assumptions have to be made during the development of a single design. A more detailed understanding would enable the uncertainty associated with a prediction to be reduced, such that a "conservative" assumption would be closer to an average predicted value, thus reducing cost while maintaining an equivalent level of safety.

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[12] Meacham, B. "The Evolution of Performance-Based Codes and Fire Safety Design Methods," *NIST-GCR-98-761*, National Institute of Standards and Technology, Gaithersburg, MD: 1998.
[13] NFPA 101, *Life Safety Code*, National Fire Protection Association, Quincy, MA: 1999.
[14] International Code Council. *Interim Report of the ICC Building Performance Codes Committee*, International Code Council, Falls Church, VA: 1999.
[15] Society of Fire Protection Engineers. *The SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design Draft for Comments of Buildings*, National Fire Protection Association, Quincy, MA: 2000.
[16] Dinenno, P. "State of Fire Safety Engineering Design Technology," in *Proceedings of the Conference on Firesafety Design in the 21st Century*, Worcester Polytechnic Institute, Worcester, MA: 1991.

Another advantage that performance-based design brings is the ability to compare different strategies to achieve a set of fire safety goals. Where different strategies are equally effective in meeting those goals, obviously the most cost effective option would be selected. However, this brings an additional benefit: the ability to apply knowledge gained through research to reduce costs in otherwise seemingly unrelated areas.

For example, an improved understanding of human behavior during egress could lead to reduced uncertainty in an egress analysis, which would lead to a smaller factor of safety applied to the egress estimation. A smaller factor of safety applied to the required safe egress time could be used to allow for a larger available safe egress time. A larger available safe egress time could be used to offset the use of furnishings that might otherwise not be acceptable, while maintaining an acceptable level of safety. The number of other similar examples is literally as broad as the mind of the engineer who is performing the design.

CONCLUSION

An increased research base will allow for the simultaneous realization of a number of benefits: improved life safety, reduction of fire related costs and improvement of environmental protection. All professionals involved in fire safety stand to benefit from an increased understanding of the physical world – fire protection engineers, product manufacturers, building owners, insurers, the fire service and the public at large.